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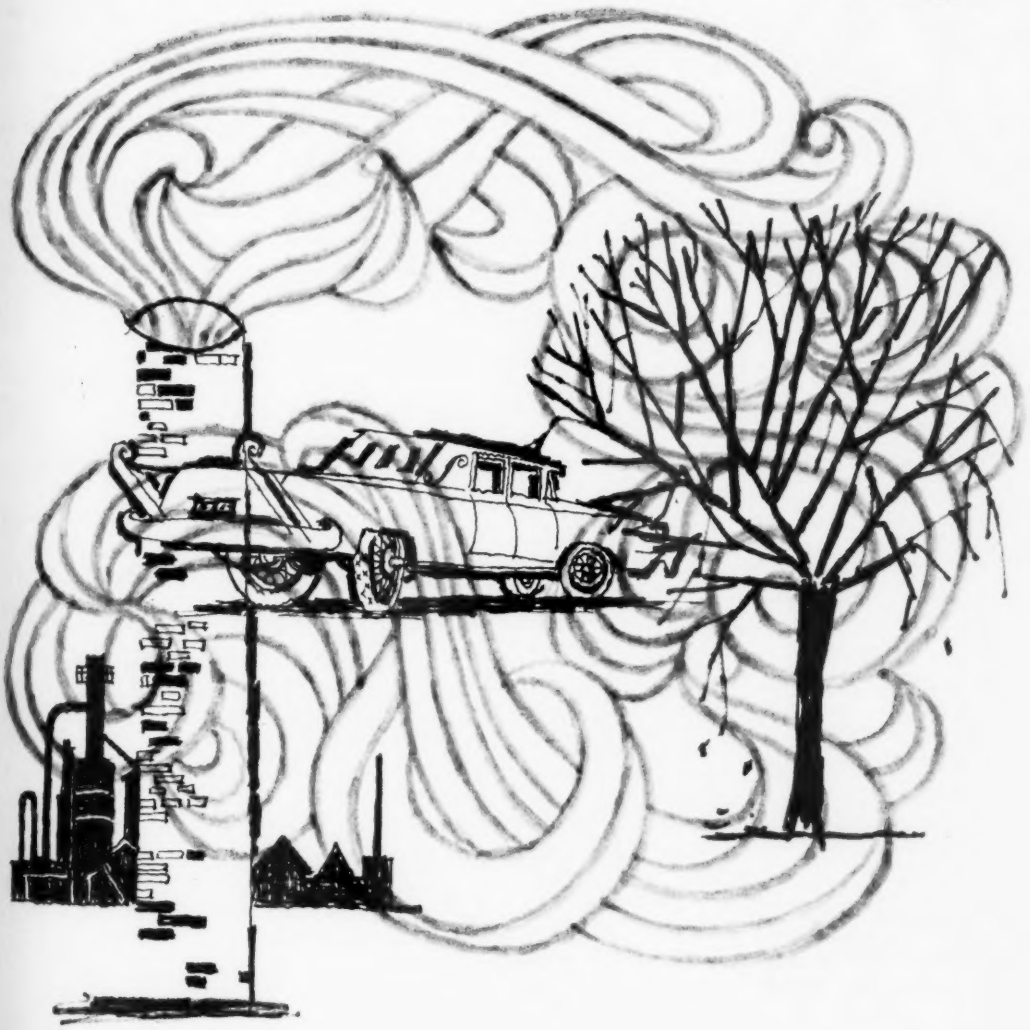

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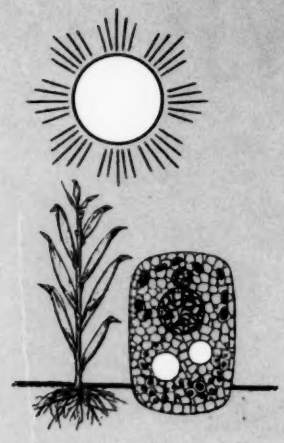

AGRICULTURAL SCIENCE REVIEW

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WHAT ARE WE TRYING TO ACHIEVE?

In many areas of our country, pollution is increasing at a rate that threatens to outdistance our most diligent efforts to control it. Some very obvious problems do need solving, and we are addressing ourselves to them. But overlying the whole area of environmental improvement is the question of what our public goals are.

What are we trying to achieve? For some, the "good life" consists of a good job, a nice home and plenty of leisure time. For others, it is a better job, a nicer home and a challenge to greater efforts.

Most of us agree that we don't want to be crowded, but do want to be near neighbors and cultural, shopping and service centers. We want to drive our cars but don't want traffic congestion. We want clean air, parks, and pure water—but at a price someone else can afford to pay. We want convenient industrial development to provide jobs, but we don't want it near where we live; and we don't want it to pollute our air.

We like natural areas to drive through and walk in, but we don't like them disturbed by "people." We like disposable containers and thick daily newspapers, but we don't like trash and smoke-producing dumps.

To sum it all up, we want to use the rich products of our society, but we don't want technology to triumph over us or to be abused by it. We resent progress that remorselessly backs us step by step to the limits of our tolerance, and stops just before it is unendurable. We have a tiny suspicion that all the chrome is just plating, and that underneath there may be some things nobody knows about—yet—that aren't good for us.

Hopefully, our progress is becoming increasingly sophisticated in this relatively new area of environmental concern. We all know where we are, and the direction in which we want to travel. But it's like going South for the winter; we're going and every mile is an improvement. There is such a long way to go that the question of where we stop is inconsequential. We may never be able to.

DONALD R. KING
Office of Science and Technology

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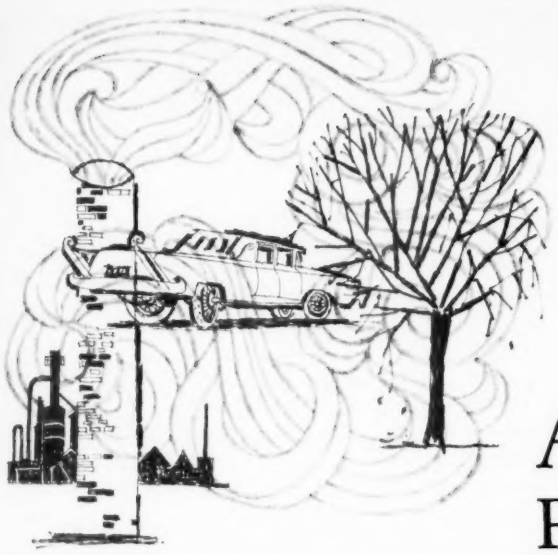

AIR POLLUTION:

Enemy Of Man And Agriculture

JOHN T. MIDDLETON

Air pollution is a threat to our civilization, the true dimensions of which we are just beginning to understand. The growing toxic burden of the atmosphere threatens both man and agriculture with striking similarity.

In terms of total economic losses, the contamination of the air is estimated to cost this country billions of dollars a year through injury to vegetation and livestock, corrosion and soiling of materials and structures, depression of property values, and interference with ground and air transportation. Losses to agriculture alone—considering injury, growth suppression, and quality changes—were recently estimated by the National Academy of Sciences to exceed $325 million annually in this country, not including damage to ornamental plants.

Of greater significance are the adverse effects of air pollution on human health. Here we are concerned not only with the threat of severe air pollution episodes capable of causing acute and sudden illness and death, but also with the hazards of prolonged breathing for months and years of the lower concentrations of air contaminants which are common in many American communities.

A growing body of scientific evidence indicates that exposure to ordinary levels of air pollution adversely affects the health of many people and is associated with the occurrence and worsening of chronic respiratory diseases and with the premature death of aged and ailing persons. Air pollution has been shown to be related to increased mortality from cardiorespiratory disorders, increased susceptibility to respiratory disease, and interference with normal respiratory function. Specific diseases associated with air contamination are emphysema, chronic bronchitis, asthma, lung cancer, and non-specific respiratory infections, such as the common cold.

The biological effects of these hazards, some of which reach man slowly and silently over decades and generations, may first begin to reveal themselves only after their impact has become irreversible.

The degree of reversibility of injury to plant life, too, is directly related to the concentration of pollutants to which it is exposed and to the duration of the exposure. Just as there have been disastrous episodes of air pollution on human health, there have also been vegetation disasters.

The most dramatic destruction of vegetation by

air pollution has taken place in the vicinity of smelters discharging large amounts of sulfur pollution into the atmosphere. In 1910 and 1911 all of the major tree species in a 5- to 8-mile radius from a smelter at Anaconda, Mont., were dead or dying. In the vicinity of the Trail, British Columbia smelter, which in 1929 emitted an average of 18,000 tons of sulfur pollution per month, plant injury was observed as far as 52 miles from the smelter. Sixty to 100 percent injury to Douglas fir, ponderosa pine, and forest shrubs occurred as far as 30 miles from the smelter in a river valley. Even though control devices were installed in 1934, by 1936 more than 80 percent of the pines that were alive in the valley had no cones.

Types of Plant Damage

THESE plant disasters are disturbing. But even more disturbing is the fact that at sulfur pollution levels routinely observed in some of our cities, many plants suffer a chronic injury frequently described as early aging. Generally, the plants most sensitive to sulfur pollution are those with leaves having high physiological activity—plants such as alfalfa, the grains, and cotton. Plants with a heavy waxy leaf such as citrus and privet are most resistant to sulfur pollution. High light intensity—especially in the morning hours—high relative humidity, adequate moisture supply, and moderate temperature—ironically, all those things which cause the plant to thrive—predispose the plant to injury.

Another pollutant that produces a characteristic injury pattern on plants is fluoride, which is emitted during the industrial processing of fertilizers, aluminum, and steel, for examples. The sensitivity of different plants to damage by fluoride varies greatly. Some plants can accumulate very high concentrations of fluoride and show no injury, whereas other plants, such as gladiolus, can accumulate injurious amounts from an atmosphere that contains only traces of fluoride.

FIGURE 1.—Smog layer over Jacksonville, Fla.

The great economic significance of plant damage from ozone, the principal oxidant in photochemical smog, was not recognized until as recently as 1958, when it was found in California that lesions in grape leaves could be produced by a 3-hour fumigation to as little as half a part of ozone per million parts of air. Tobacco, too, is sensitive to ozone—about one-tenth of a part per million—and tobacco plants are increasingly used to detect ozone. Ozone is now recognized as a major threat to leafy vegetables, field and forage crops, shrubs, fruit and forest trees—particularly conifers.

Ozone offers an example of the similarity of pollutant damage to both plants and animals through the same basic chemical processes. Studies show that ozone oxidizes sulphydral groups in enzyme and other components of plant cells to inhibit plant metabolism and cause cells to leak their contents. Ozone also reacts with components of the lung tissue of mammals to alter cell-wall permeability and to lead to pulmonary edema. Ozone breaks down the elements in green plants (chloroplasts) which carry on photosynthesis and, similarly, damages human red blood cells by breaking down unsaturated fatty acids in cell membranes. As with other pollutants, the degree of reversibility or irreversibility of the effects of ozone depends upon the length and concentration of exposure in both plants and man.

PAN, peroxyacetylnitrate, another of the oxidants in photochemical smog, is extremely toxic to many field and vegetable crops as well as to several ornamentals. Woody shrubs and trees and many field and vegetable crops are relatively resistant to PAN.

Under controlled conditions, automobile exhaust exposed to ultraviolet light—simulating photochemical smog conditions—has produced characteristic smog injury in plants. Some of the injuries were attributable to ozone and PAN; others to nitrogen dioxide.

Still other injury patterns indicate that irradiated auto exhaust contains other unidentified pollutants harmful to plants. Most of these artificially induced damages have been seen in the field.

Photochemical smog has caused a serious decline in citrus and other important crops in California, but, of course, smog is no longer confined to that area. Smog damage has now been reported in 27 States, the District of Columbia, Canada, and Mexico. Along the entire eastern seaboard from Boston to Washington, D.C., smog now causes agricultural losses comparable to those in Southern California. These same damaging pollutants are to be found beyond the Americas in such places as Australia, western Europe, and eastern Asia.

Scope of Knowledge

THE visible effects of most of the common toxicants are fairly well known. A competent observer in the field usually has no difficulty in identifying the necrotic lesions that sulfur oxides or fluorides induce on plant leaves. The injury patterns produced by ozone and PAN are not difficult to distinguish. Scientists also have considerable knowledge of the cellular breakdown which takes place within leaves.

Knowledge is much less complete in regard to the possible effects of air pollutants on such matters as the growth, yield, nutritional quality, and survival of plants. We do know that severe leaf injuries by pollutants will affect growth and perhaps survival of trees, which take repeated exposures year after year. There is reasonable evidence that oxidants or fluorides, even at levels that do not mark the foliage, may significantly reduce growth rate and fruit quality in some cases.

The entire analysis of the effects of air pollution on plants is complicated by two important influences—genetics and environment. As for genetics, different species are expected to respond differently to air pollution, but the variations within species are often just as great as the differences between species. As for environment, such factors as rainfall, temperature, wind, nutrition, soil moisture, and management practices all have their different effects. For example, it appears that much less oxidant is required to damage plants in the humid East than in the arid West, but this effect may derive in part from an interaction between environment and genetics.

In addition to all this, the pollutants themselves interact with each other in the atmosphere and also interfere with each other's effects within the plant, so that non-toxic levels of sulfur dioxide greatly enhance the toxic effects of ozone. Similarly, the damaging effects of sulfur oxides on man are enhanced and aggravated by the interaction of these oxides with particulate material.

All this demonstrates the complex nature of the

effects of air pollution on agriculture, and, at the same time, illustrates the similarity of the threat that air pollution poses to all things which depend upon the air for life. This threat is reflected in three levels of effects of air pollution: (1) The immediately and easily discernible effects from high concentrations of contaiminants, (2) the more slowly developing chronic effects from routine concentrations over longer periods of time of which we are now becoming aware, and (3) the long range, genetic effects about which we can only make some educated guesses.

Although there will be a continuing effort to increase our understanding of the nature of air pollution and to improve the methods and techniques for its control, much can be done today. The severity of existing air pollution problems requires the reduction of air pollution from existing sources. As our burgeoning economy builds and rebuilds itself over the coming years, advantage must also be taken of the opportunities to restore the quality of our air environment at the earliest stages of land use planning and facilities design.

Early Control Efforts

As recently as the early 1940's, air pollution was thought to be a relatively simple problem of black smoke, and confined to a relatively few Eastern and Midwestern industrial cities. The technology for controlling this kind of air pollution consisted of improvements in combustion practices, restrictions on the kind of fuel used, and in some cases, devices to control smoke emission. When smoke became intense enough to generate a public clamor for relief, this technology was applied. With considerable help from the fortuitous change from steam to diesel-powered locomotives and the substitution of gas and oil for coal in space heating, the atmosphere of these cities visibly improved.

The experience of Los Angeles—whose explosive growth in the 1940's and 1950's contributed to its becoming the first major city to feel the full impact of the modern air pollution problem—awakened public recognition of the fact that the problem we now face is much more than a mere smoke nuisance or a bothersome inconvenience.

In fact, the difficulties in California, where the smog problem emerged and grew to serious proportions within a very few years, were, perhaps, a blessing in disguise for the rest of the Nation. They provided advance warning of a problem which was developing more slowly in other cities and towns.

By 1955, the Nation had begun to respond. The initial ground swell of public reaction helped bring about passage of legislation authorizing the Department of Health, Education, and Welfare to undertake the first Federal air pollution control program.

Actually, the 1955 legislation authorized little more than a token effort. It called on State and local governments to assume the basic responsibility for preventing and controlling air pollution and authorized the Federal Government to conduct research and provide technical support.

Still, the first 8 years of operation of this program took much of the mystery out of the contemporary air pollution problem. The Federal effort helped to produce a substantial improvement in scientific knowledge of the problem. It increased the understanding of its impact on public health and welfare. It revealed the existence of techniques for controlling a number of the important sources of air pollution, and, in many cases, the need for new and better control techniques.

The first substantive result of the concern of the scientific community and the public was the passage of the Clean Air Act of 1963. This legislation opened the way for real progress.

In 1963 expenditures for State and local air pollution control programs totalled $13 million. In 1967 they totalled $26 million.

Prior to passage of the Clean Air Act, only 16 States had passed air pollution control legislation. At present, 46 States have done so.

Following pioneer work in controlling air pollution from motor vehicles in California, the Congress amended the Clean Air Act in 1965 to authorize the Secretary of Health, Education, and Welfare to set national standards on emissions from new motor vehicles. The first Federal emission standards, which were established in 1966, went into effect with 1968 model cars and light trucks and will apply also to 1969 motor vehicles. The Secretary has set more restrictive standards to go into effect with the 1970 and 1971 models.

Under the Clean Air Act, the Secretary of Health, Education, and Welfare has initiated several interstate abatement actions in various parts of the country. These have stimulated local and State control efforts which should improve the quality of the air

breathed by millions of people.

While this progress was heartening, it fell far short of the need. Since 1963, trends of urban, industrial, and technological growth—hallmarks of our era—have continued to rise. We continue to generate more electric power, to drive more automobiles, and to produce more products, and the prediction is for more of the same in the decades ahead. Unless air pollution control efforts are greatly improved, a problem which is now serious in many places and critical in some promises to become critical in many and tragic in some.

Air Quality Act

In recognition of these facts, Congress in 1967 passed the Air Quality Act. This act gives the Nation for the first time the opportunity to control air pollution on the basis of scientific knowledge, and at the same time provides a means by which this knowledge can be translated into effective social and political action.

It provides a comprehensive plan for the control of air pollution which will enable all levels of government, as well as the private sector, to discharge their respective responsibilities on a regional basis, in a logical and orderly way.

The first step of the control procedure prescribed by the act was essentially accomplished on January 16, 1968, when the Department of Health, Education, and Welfare defined eight broad atmospheric areas covering the 48 contiguous States. Areas covering Alaska and Hawaii will be defined later. Each of the atmospheric areas represents a segment of the country in which climate, meteorology, and topography—all of which influence the capacity of air to dilute and disperse pollution—are generally homogeneous.

The act further requires the Secretary to define those geographical regions in the country where air pollution is a problem—whether interstate or intrastate. These air quality control regions will be designated on the basis of meteorological, social, and political factors which suggest that a group of communities should be treated as a unit for setting limitations on concentrations of atmospheric pollution.

The task of designating air quality control regions is moving rapidly ahead. Thirty-two urban areas are expected to be designated by mid-1969. The first four—the interstate metropolitan areas of Washington, New York, Philadelphia, and Chicago—are planned for 1968.

At the same time that he is designating air quality control regions, the Secretary is required to publish air quality criteria for those pollutants he believes may be harmful to health or welfare, and to publish related information on the techniques which can be employed to control the sources of those pollutants.

The criteria will describe what is known of the predictable effects of exposures to various concentrations of pollutants for various lengths of time. They will provide the States with the latest scientific information for developing standards of air quality for the protection of public health and welfare in the regions designated by the Secretary. These air quality standards will become the goals of the control efforts in the regions.

Development of Criteria

Considerable progress has been made in developing air quality criteria. As required by the Air Quality Act, a National Air Quality Criteria Advisory Committee, with a membership broadly representative of industry, the universities, conservation interests, and all levels of government, has been established. This committee is giving advice to the National Air Pollution Control Administration (NAPCA) on policies and procedures under which criteria will be issued, and is assisting in reviewing draft criteria documents.

Several such documents are presently in the draft stage. A draft of criteria for total particulate matter has been prepared by NAPCA with the help of university consultants working under contract. The final document is expected to be published in 1968. The sulfur oxides criteria document, originally issued in March 1967, will be reissued in accordance with the provision of the Air Quality Act which requires that any criteria issued prior to the act be reevaluated. The revised document will be published concurrently with the document on particulates. It is intended that the simultaneous issuance of criteria on particulates and sulfur oxides will underscore the importance of the effects that the combination of these pollutants in the atmosphere produces and will thereby emphasize the need for giving simultaneous attention to controlling them both.

With the help of consulting scientists and the

California State Department of Public Health, NAPCA has prepared a preliminary draft of criteria for photochemical oxidants, as well as complementary documents on nitrogen oxides and organic compounds, including hydrocarbons. This group of criteria is expected to be issued during 1969. NAPCA is also working with the California State Department of Public Health on a draft of the carbon monoxide criterion to be issued along with the other criteria primarily concerned with pollution from the motor vehicle.

Negotiations are underway with the Department of Agriculture for the preparation of criteria on fluorides. Issuance of these criteria is also planned for 1969. Consideration is being given to developing and issuing criteria for several other classes of air pollutants including such diverse substances as carcinogens, metals, odorous compounds, pesticides, pollens, and radioactive materials.

Parallel with the development of criteria for various air pollutants, NAPCA is preparing reports on the available technology for controlling the sources of these pollutants. These reports will identify the best methods available for reducing pollutant emissions—whether these techniques involve the application of control equipment, changes in fuel use or industrial processes or any other practical approach. The reports will include the costs of applying these techniques.

A report on the available systems and devices for controlling particulate emissions from a wide variety of mobile and stationary sources and a comprehensive evaluation of control systems and techniques that are available for controlling sulfur oxides pollution from fuel combustion processes will be published along with the criteria for those pollutants.

Under the act, as soon as a region has been designated, and as soon as a criterion on a pollutant or a combination of pollutants and the related control technology of the sources of these pollutants have been published, the State or States responsible for the designated region are on notice to develop standards for the region on the pollutants covered by the criterion, and to develop plans for implementing the standards. They have 90 days to write the Secretary indicating that they intend to set standards, 180 days to submit proposed standards for the Secretary's review, and a further 180 days to submit implementation plans. If the Secretary finds that the air quality standards and plans are consistent with the criteria and the related control technology information, then those standards and plans will take effect. If he finds that they are not consistent, he can initiate action to insure that appropriate standards and plans are established.

This, in brief, is the mechanism established by the Air Quality Act which will begin the control of air pollution on a regional basis in this country. There is sufficient technical know-how to achieve a significant degree of control of many of our most serious sources of pollution and the most immediate need is to guarantee the application of this technology in adequate measure. This is a challenge which clearly calls for the development of appropriate control programs at all levels of government.

It is also clear that the fundamental knowledge of air pollution and control technology must be improved, not only to better cope with today's air pollution problem, but to arm the country against future problems.

The Air Quality Act makes possible a greatly accelerated program of research. It will afford the opportunity to expand and refine our knowledge of the effects of air pollution; to acquire a more fundamental knowledge of how pollutants move about in the atmosphere, how they are transformed, and how they are removed from the atmosphere; to develop better tools for measuring air pollution; and to perform whatever research is necessary to develop control techniques for those sources of pollution for which no feasible control methods exist.

Research Needs

ALTHOUGH it is known that air pollution is dangerous, this knowledge has been particularized very little. It is not known exactly how dangerous it is or exactly what fraction of it—or combinations of fractions—are responsible for what particular damage, and there are many other areas where suspicions are inadequately supported by credible data.

One large region as yet scarcely touched is behavioral toxicology. It must be learned how to relate ambient levels of carbon monoxide to degradation of response time and mental acuity. The relationship must be discovered between exposure to the odors from, say, a meat rendering plant or a diesel bus to feelings of malaise, irritability, and other symptoms which must at some date be factored into

air quality standards.

Much more data must be developed on synergism. The effects of pollutants on subjects with infectious diseases, on subjects with special sensitivities, and on subjects whose defenses against injury have been otherwise lowered must be more intensely and more broadly investigated.

In a widely different field, significantly greater economic studies are needed.

We must determine how much damage to materials and plants is caused by exposures to varying levels of pollution. Studies must also be conducted to relate control expenditures to economic benefits.

A great deal of basic knowledge on the mechanics and chemistry of air pollution has to be gathered. Knowledge of the life cycle of pollutants, for instance, is mostly suppositional. The natural cleansing processes of the atmosphere are not fully understood, and it is necessary to base some calculations for the transport and dispersion of pollutants on some rather shaky assumptions.

For most places in the country today, it is not even possible to say precisely what the levels of all the important pollutants are at any given moment, nor how they vary from hour to hour, day to day, and season to season. In some cities, the National Air Pollution Control Administration has installed continuous air monitoring stations, and these stations monitor half a dozen of the most serious pollutants continuously. In many cities, however, measurements are made only in the downtown area and the knowledge of pollution throughout the rest of the city and its environs is largely derivative.

Another area where scientific help is needed is in the development of control technology.

NAPCA has underway a closely coordinated program involving 46 industrial groups, research firms, and other non-Federal organizations in developing techniques and devices for controlling sulfur pollution. The program focusses on processes with enough history and promise to merit large-scale investigation. These comprise limestone or dolomite injection, including dry processes and injection coupled with water scrubbing, several alkalized alumina sorption processes; and processes that would separate sulfur from pyrite coal to produce not only a clean fuel but a useable sulfur byproduct.

A similarly coordinated program for nitrogen oxides from stationary sources is being initiated. NAPCA is supporting a comprehensive state-of-the-art and planning study in this area, which will permit bench and pilot studies to begin within a year for all significant sources of nitrogen oxides. By the middle of 1969 it is expected that private research talent will be mobilized, feasibility studies will be underway, mathematical models of heterogeneous combustion reactions will have been developed and partially verified, work will have begun on design and pilot testing of small and intermediate combustion units with minimum production of nitrogen oxides, and data analysis and conceptual designs of large boilers will have begun.

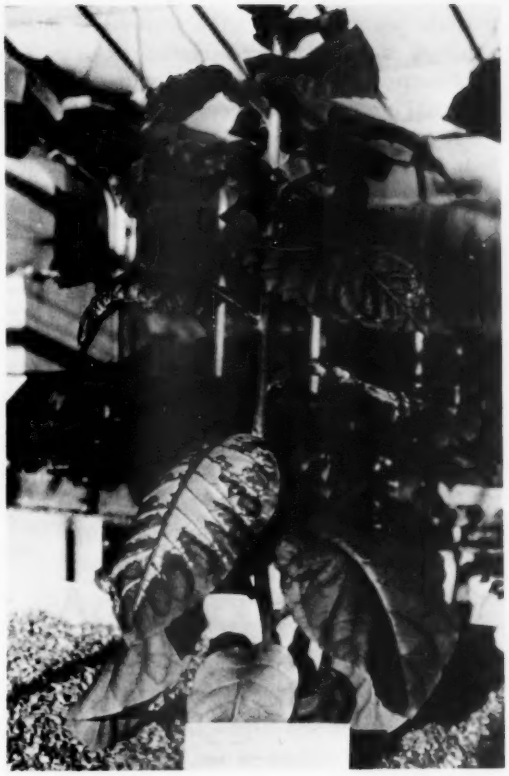

FIGURE 2.—This tobacco plant shows Type C injury from irradiated automobile exhaust in studies conducted by NAPCA.

There is a great deal more to be done than can be discussed here. Methods of incineration must be improved. In fact, many existing control devices should be improved and made more economical. NAPCA expects to stimulate the research which will result in markedly cheaper and more effective elec-

trostatic precipitators, inertial separators, filters, scrubbers, and catalytic combustion schemes. Beyond control devices there is the enormous field of industrial process modification.

There are also many remaining unsolved problems with regard to the exhaust from automobiles and other vehicles. The importance of the diesel problem as it relates to smoke and odor control, the importance of various vehicular emission sources and the need for control and development of test procedures for these sources from all types of vehicles, the need for control of nitrogen oxides from vehicular sources, the problems of maintaining control devices to insure their continued operation and upgrading such devices so that they will be essentially maintenance free—these are only a few of the areas in which the National Air Pollution Control Administration is continuing research in its own facilities and through grant support or contract with various private and public organizations.

And there is infinitely more to be accomplished.

True, we have made some achievements. But to continue the trend at a level commensurate with the rising needs, we must seek a fresh perspective and think and plan along new lines. The old pleas that our country is too technically unsophisticated to conduct its business without fouling the air seem weak when one considers the startling achievements in space technology. Actually, the challenges in finding ways to restore the quality of environment on which life depends are too numerous to list. Hopefully, the Air Quality Act of 1967 will provide the opportunities to meet the unprecedented challenges necessary to win the fight against polluted air.

Goals will be set and discarded. Criteria and standards will be set and revised. The war to keep man from spoiling his environment will never end, but we can and must reach a point where we can breathe the air about us with assurance that it is not harmful.

Progress in the IBP

NOW that the first large-scale grants have been made for support of the International Biological Program in the United States, scientists here are becoming more optimistic over the future of the program. Of particular interest to agricultural scientists is the grasslands study, which is a part of IBP research on ecology of the environment.

Site for the grasslands study is near Nunn, Colorado, about 38 miles from Colorado State University and 75 miles from the University of Wyoming—the two principal universities involved. Pawnee, as the site is called, is located on the 15,000-acre Central Plains Experimental Range of the Agricultural Research Service. In addition, 110,000 acres of the nearby western portion of the Forest Service Pawnee National Grasslands will be used for some of the studies.

According to George M. Van Dyne, Biome Director and principal investigator, the overall research plan includes four components: (1) abiotic factors such as soil, climate, and water; (2) the "producers"—plants that manufacture food; (3) the "consumers"—animals that eat plants and each other; and (4) the "decomposers"—bacteria and fungi that break down waste products and tissues and regenerate the soil.

During the first year, 11 research projects involving 26 investigators will be started. One interesting question to be studied is whether native species such as bison and antelope are more efficient and better adapted to the grasslands than those species—cattle and sheep—imported by man.

Other initial studies will use advance equipment and techniques such as neutron probes for measuring soil moisture, capacitance meters to measure changes in the total amount of herbage, microwave radar systems for measuring evapotranspiration, and low level remote sensing to detect vegetation and soil differences.

The new IBP study will place heavy emphasis on the interdisciplinary approach to environmental biology through the use of mathematics, systems analysis, and computers. Of the first six graduate students selected to participate, only one comes from the traditional biological fields.

Leaders of the new IBP study believe it holds much promise for providing answers to the very disturbing problems man faces in maintaining environmental quality.

Advances in PLANT VIRUS RESEARCH

J. B. BANCROFT

ALTHOUGH plant virus diseases undoubtedly predate the cultivation of useful plants, their impact on crop plants was not realized for a variety of reasons until the present century. As the realization of the serious effects which viruses had on plants increased, man's understanding of the nature and behavior of viruses likewise expanded. But despite the sometimes dramatic advances in virus research during the past few decades, virus diseases of plants still persist as a major concern of agriculture throughout the world—for reasons that are not all scientific.

Our knowledge of plant viruses has increased and accumulated at a pace comparable to that in other areas of modern biology. People of widely different talents and interests have contributed this new information through a number of different pathways—occasionally in concert but usually separately—so that to summarize advances in plant virus research is to summarize approaches in many areas of biology often related only by the object being investigated. I shall attempt to explain the nature of what seems to me to be some of the important virus research done during about the past 10 years—particularly in research concerning the structure of virus particles and their biological activity—so that some idea of the scope and direction of original virus research may become evident.

How Viruses Are Built

WITH one possible exception, all viruses so far found infecting higher plants are ribonucleoproteins. There is probably nothing particularly fundamental about this, and plant viruses are not greatly different—except in regard to their hosts and methods of entry—from many viruses which attack bacteria and animals. Most plant viruses are what is known as regular viruses in that their construction is characterized by some regular arrangement of many identical functionally equivalent protein subunits formed about RNA which is usually but not always single stranded. Such regular arrangements result in essentially either rod-shaped or spherical struc-

tures. The classical structure of a rod-shaped virus and the one about which most is known is tobacco mosaic virus (TMV). This virus has a molecular weight of about 40×10^6 avograms (one particle weighs 6.6×10^{-17} gm) and contains close to 5 percent RNA as a single large covalently-linked molecule. The studies leading up to the elucidation of the structure of the protein coat of TMV and its relationship to the viral RNA may serve as an example of how a virus is regarded physically and how results from different methods are correlated.

Studies using X-ray analysis provided us with the knowledge that 49 protein subunits occur in three turns of the coat protein helix of TMV (fig. 1) and that the pitch of the subunits is 23 Å, so that the three turns cover a linear distance of 69 Å. Through electron microscopy, the insight was gained that the length of the infectious unit is 3,000 Å, so it can easily be determined that the coat would contain 2,130 protein subunits. Since the molecular weight of the virus and the percentage RNA were known, it therefore followed that the molecular weight of a single protein subunit would be about 18,000 avograms, if all the different analyses were correct. Direct confirmation that they were came from yet other approaches. Hydrodynamic studies on isolated TMV protein subunits gave a molecular weight of the correct order. Chemical analyses of increasing sophistication resulted in a molecular weight of 17,506 for the primary chemical unit, and the molecular weight of the total coat divided by 17,506 gives 2,170 protein subunits—a value close to that predicted from X-ray evidence. Each protein subunit contains 158 amino acids and the sequence of these amino acids is now known, thus making possible the interpretation of genetic experiments to be described later.

Other results from X-ray analyses showed that the TMV–RNA molecule is located between the protein subunits at a distance of about 40 Å from the center of the particle which has a central hole of 40 Å and a maximum diameter of 180 Å. The RNA molecule has a molecular weight of 2×10^6 avograms and contains about 6,400 nucleotides. The size of the RNA is much too small to contain enough information to code for a single protein of a molecular weight of 38×10^6. It was this size limitation in addition to early structural considerations that led to the idea of the necessity of small repeating

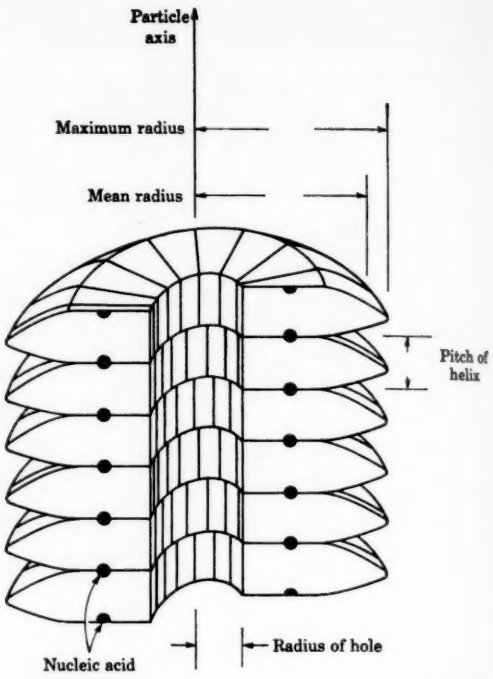

FIGURE 1.—Cross-section diagram along a portion of the length of the rod of tobacco mosaic virus. (Adapted from *The Chemistry of Viruses* by C. A. Knight)

subunit structures in the construction of virus protein coats.

The concept that a virus could be regarded as representing an accurate self-assembly first came from the studies on TMV–RNA and the protein subunits. Thus, if these constituents are mixed together in their normal proportions under the correct ionic conditions, they assemble to form rods indistinguishable from TMV. If no RNA is present, then rods are also formed but their subunits assume a stacked disc rather than helical array. "Mixed viruses," in the sense that RNA from one TMV strain can be combined with the coat from another, were made and resulted in unequivocal demonstrations of the biological primacy of RNA, for their progeny were not affected by the "foreign" coat protein. Further studies also showed that coat protein plays no role in the determination of host range, although it does in bacterial and animal viruses which do not have to contend with the plant cell wall and require no mechanically-induced wound to gain entry. Work with TMV, incidentally, gave the first

proof that RNA by itself could be infectious.

Many plant viruses are spheres, and with these the structural problem is in some ways more complex than with TMV. Nonetheless, it has been solved partly from theories formulated on geometric and physical grounds to give what is known as the "quasi-equivalence" theory. This theory predicts that regular spherical viruses will be composed of 60, or multiples of 60, asymmetric units ranged about five, three, two (fig. 2) symmetry axes giving icosahedral symmetry. It is impossible to arrange more than 60 identical units on the surface of a sphere so that they are identically situated and bonded in strict equivalence. But if certain permissable bond deformations are used, then quasi-equivalence is possible so that sets of 60 units may be used.

The advantage of icosahedral symmetry over other possible types of cubic symmetry is that it allows the greatest number (60) of identical asymmetric units to build a sphere in which the units are packed alike. It is also advantageous in terms of surface-to-volume ratio and this has not been overlooked by architects. Realizing this, let us examine the physical structure of a spherical virus which has 180 asymmetric units.

Cowpea chlorotic mottle virus (CCMV) has a dry diameter of 250 Å, a molecular weight determined by hydrodynamic means of 4.6×10^6 avograms, and contains 24 RNA which extends up between the protein subunits helping to stabilize the virus. If the virus is examined in the electron microscope, knobs which are called morphological units or capsomeres may be seen. It can be deduced that there are 32 of these knobs. By the quasi-equivalence theory we know that we must arrange 180 asymmetric or structural units into 32 groups. An icosahedron has 12 fivefold (five identical rotation positions) vertices upon each of which is situated a capsomere composed of five structure units. Such a capsomere is called a pentamer or penton and 12 of these would contain 60 structural units. The icosahedron has 20 threefold faces and on each of these is located a capsomere called a hexamer or hexon composed of six structure units and containing, all told, 120 structure units. Thus, all 180 structure units have been accounted for. The molecular weight of the protein subunits has been determined chemically and each has a value of 19,600 avograms. The protein coat of CCMV, derived from the hydrodynamic molecular weight of the virus minus the weight of RNA, is 3.5×10^6 avograms. This weight divided by 19,600 equals close to 180, so that we infer that the structural considerations predicted by the quasi-equivalence theory are correct.

Recently, it has been found that the protein subunits of CCMV may be made to repel each other and separate from the RNA under conditions favorable to their structural integrity. The demonstration that a spherical virus such as CCMV, as well as the rod-shaped TMV, can be regarded as a self-assembly system followed, for when isolated subunits and RNA were added together correctly, CCMV resulted. The conditions for self-assembly for TMV and CCMV suggest that hydrophobic associations predominate with TMV, whereas electrovalent ones do for the sphere. The sphere can be assembled around a number of different types of RNA—including that of TMV—to give spherical particles.

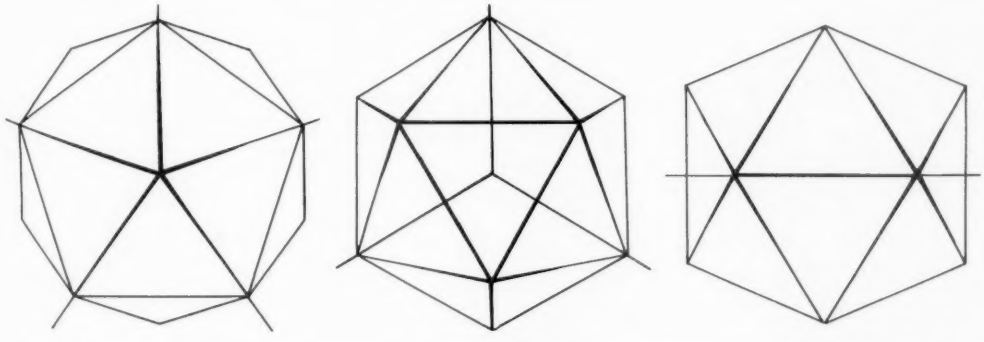

FIGURE 2.—Axes of symmetry for a regular icosahedron—a figure with 12 corners, 20 faces and 30 edges. (Adapted from The Structure of Viruses by R. W. Horne)

Various synthetic homo and heteropolynucleotides have also been employed, and even polyvinylsulphate can be used for the nucleation process. Three spherical viruses have now been disassembled and their proteins can be made to form particles which individually contain subunits from each, indicating some latitude in the protein-protein interaction just as there is with the protein-nucleic acid association. If the protein of CCMV is properly manipulated in the absence of RNA, then long tubes which are theoretically permissible and which are built of hexamers and rounded off with pentamers actually assemble. A number of other forms can also be made, but the tubes are of interest because they are built like structures found in virus-infected tumor cells of vertebrates. Neither type of tube is infective and their appearance *in vivo* may represent a metabolic mistake probably resulting from an imbalance between the rates of synthesis of viral protein and nucleic acid. The details of the structure of the tubes were obtained by an increasingly used method which gives what are called "optical transforms". The method involves passing coherent light, such as emitted by a laser, through an electron micrograph negative of a structure such as a tube, thus treating it as a diffraction grating.

Strains and the Genetic Code

THE question of what differentiates one plant virus from another is somewhat a matter of viewpoint and necessity. Nonetheless, it is of considerable interest and has wide implications. On the practical side, strains of the same plant virus, not surprisingly, have the same general intrinsic properties even though they may incite different symptoms so that if a quick way of typing a virus in a general class is available, significant etiological questions can be rapidly answered. It has been known for a long time that strains of a single virus have antigenic groups in common, and it is partly this characteristic which has spurred the great interest among pathologists in serological methodology. In order to obtain virus-specific antisera, it is best to inject animals with pure viruses, and the various and sometimes expensive techniques of virus purification commonly receive considerable attention for this and other reasons. The development of density-gradient centrifugation has been of tremendous importance.

The composition of the protein coat of a virus reflects the nucleotide sequence of part of its RNA. This relationship has been exploited as a means of testing genetic code assignments—that is, the specification of amino acids by nucleotide triplets as determined by other methods. TMV was one of the first viruses to be treated with nitrous acid to form mutants. Nitrous acid oxidatively deaminates primary amines such as cytosine to form uracil, and adenine to form hypoxanthine which base pairs like guanine. Knowing this, it is possible to check if certain amino acid replacements found in TMV coat protein after the multiplication of TMV RNA treated with nitrous acid are permissible in terms of a universal genetic code. For example, amino acid replacements from aspartic to glutamic acid occur. The codon (nucleotide triplet which codes for an amino acid) for aspartic acid is GAU so that the changed triplet would be GGU, which is one of the codons for glutamic acid and follows the rules imposed by the use of nitrous acid.

Other confirmatory conclusions, based on knowing the primary structure of TMV protein, have also arisen from this general type of approach. For example, it is known that: (1) The genetic code is not overlapping in TMV—that is, simultaneous replacement of two adjacent amino acids has never been observed. (2) The code is degenerate—meaning that a single amino acid can be coded for by more than one nucleotide triplet. (3) Symptom mutants can occur with no corresponding change in coat protein—showing that the RNA codes for more than coat protein. This is not unexpected since a single protein subunit of TMV contains only 158 amino acids, which is equivalent to 474 nucleotides equal to about 8 percent of TMV–RNA. (4) The plus strand of RNA (that is, the strand inside TMV) codes for coat protein, whereas its complementary or minus strand made in replication does not. This last point has also been deduced from quite different approaches in which RNA from a component of alfalfa mosaic virus and a satellite virus associated with tobacco necrosis virus have been used as messenger RNA's in cell-free bacterial systems to specify coat protein.

Multiplication and Interactions

THE process of "mechanical infection" (infection induced by rubbing and wounding the leaves of a

healthy plant in the presence of inoculum) with a plant virus is not really understood. There is good evidence, gathered by following the sensitivity to ultraviolet light of infections initiated by virus and RNA, that coat protein is stripped from virus prior to the multiplication of RNA. How the virus becomes uncoated is not known, nor are the preferential sites of entry, although, as to the latter, wounded ectodesmata which are small external protoplasmic projections, believed to be similar to the internal plasmodesmata, and distinct from stomata and hydathodes, are gaining in popularity as a possibility. The RNA is assumed, by analogy with results from certain bacterial viruses, to initiate the production of enzymes (polymerases or replicases) responsible for the multiplication of viral RNA.

The functions of these enzymes are largely insensitive to antibiotics such as actinomycin D and thus are quite different from the DNA-dependent RNA polymerases found in healthy cells. That differences occur is well worth emphasizing for if the situation were reversed, it would mean that we could selectively stop the specilazied machinery used by RNA viruses to multiply. This would mean the control of plant viruses—and many others. The viral RNA replicates in what is called a semi-conservative asymmetric fashion, which means that complementary minus-RNA strands are made less rapidly than the plus strands formed on them and found in the mature virus particles. The actual sites of replication are not entirely clear, partly because different stages of infection and assembly have often been considered. But there is fairly good evidence that virus-directed RNA synthesis occurs in the nucleoli for the rod-shaped viruses so far examined and in the cytoplasm for spherical viruses. In any event, the replication scheme requires that double-stranded RNA actually occurs and such RNA has, in fact, been isolated from virus infected plants.

It is assumed, largely by analogy, that plus strands of RNA—which probably spread from cell to cell through plasmodesmata—become associated with ribosomes, upon which sites, with the help of other cell constituents, coat protein is made as subunits. These subunits aggregate by self-assembly mechanisms, such as illustrated earlier around viral RNA, to form mature virus particles, which are essentially inert metabolically but can be spread through the vascular system in the plant or to other plants in ways to be discussed.

For many years, it was believed that in the initiation of infections like those just described, a single virus particle carried all the information necessary for all the functions of replication and maturation regardless of whether the virus sedimented as a single species, like TMV or CCMV for instance, or whether it had associated with it other nucleoproteins partially deficient in RNA which sedimented at a rate slower than that of the virus. However, these multicomponent viruses are common, and it is becoming increasingly clear that each separate component has a function of its own. The components interact and contribute to the survival of the virus.

There are three principal types of interactions.

1. With some viruses, two nucleoproteins occur, each containing different amounts of RNA with similar but not identical base ratios and protected by coat protein of the same composition. The different particles must interact to cause most and perhaps all infections, neither particle type by itself being nearly as infectious as when mixed. This phenomenon is so far usually associated with spherical viruses such as those belonging to the squash mosaic and tobacco ringspot virus families.

2. Another system is exemplified by viruses such as tobacco rattle virus which has rods of two lengths containing similar but not identical RNA molecules surrounded by the same protein type. The long rod particles cause infections in which the progeny is not coated by protein. If the short particles, which are not infective by themselves, are added to the long rods, then coat protein is made. The long and short rods have different complementary functions.

3. The third principal type of interaction would be that where a defective virus called satellite virus cannot multiply by itself but can in the presence of an antigenically unrelated virus called tobacco necrosis virus. The RNA of the satellite virus is very small and may be able to code for only one or two polypeptides, one of which is coat protein. This is distinct from that of the necrosis virus, which presumably induces the production of the enzymes required for the satellite virus to multiply.

There are no definitive data that interactions other than the essentially complementary types just described can occur with plant viruses. It is conceivable, however, that recombinational events may be associated with the tomato spotted wilt virus.

Viruses and Their Vectors

IT is characteristic of many different plant viruses that they are spread naturally and specifically by a number of different living agents called vectors among which are insects, mites, nematodes and fungi. Most viruses which have vectors are transmitted by insects, usually of the sucking type. If the vector is an aphid, then the virus will usually be of the nonpersistent type. This means that the aphid will remain viruliferous usually only for a matter of hours and can acquire and transmit virus in a matter of seconds. It has been shown in experiments in which bared stylets (the sucking organs of the mouth parts) have been treated with formaldehyde or irradiated on various parts with ultraviolet light, that nonpersistent viruses are carried on the ends of the vector's stylets. This association is not simply mechanical, however, because viruses such as TMV which reach very high concentrations in the plant host are not aphid-transmitted normally, so that specificity does exist but its nature is not known. Nonpersistent viruses also are usually mechanically transmissible and generally cause symptoms of the mosaic type.

A large number of viruses are not mechanically transmissible and most of these are persistent—that is, their insect vectors remain viruliferous for long periods of time, sometimes up to the life of the insect. These viruses are usually transmitted by leafhoppers and are called circulatory, since it is necessary that they go into the insect's body before they are transmitted efficiently. Some of the viruses are propagated in that they multiply inside the insect's body and some of these can be transmitted transavarially. This latter characteristic was used with clover club leaf virus for the first unequivocal demonstration that a virus which can multiply in a plant can also multiply in an insect.

A very significant advance has recently been made in this field: development of the technique for growing monolayer tissue cultures originating from embryonic leafhopper tissue. This makes possible for the first time biological experiments with a group of plant viruses which could be comparable in precision to those performed with animal and bacterial viruses. In addition, used together with fluorescent antibody techniques, it opens the possibility of rapid indexing procedures which would be of considerable practical importance.

Some persistent viruses, such as the incitant of the barley yellow dwarf disease, are similar in their physical properties to the mechanically-transmitted viruses, but many are quite complicated and have properties similar to some viruses which infect animals. Thus, the wound tumor and rice dwarf viruses are large (600–700 Å diameter) icosahedral viruses which contain double-stranded RNA. These are physically, but not serologically, similar to the reoviruses which are pathogenic to humans. Another group of persistent viruses such as lettuce necrotic yellows virus and potato yellow dwarf virus belong to a new group of membrane-bound, bacilliform-like viruses which seem to contain structural lipids and which are morphologically similar to the vesicular stomatitis virus pathogenic to vetebrates. The complexity of some persistent pathogens seems to be reaching new heights, if current speculation about the incitant of the aster yellows disease being a mycoplasma proves to be correct. A mycoplasma in this case is considered essentially as a protoplast which is quite distinct structually and metabolically from a virus—as are all organisms.

A number of viruses are transmitted through soil to plant roots. The largest easily classified group of these viruses is collectively called ringspot viruses. These are mechanically transmissible, spherical, have two or three sedimenting components, and cause ringspots on the leaves of some of their host plants. They are transmitted by members of only two genera of ecto-parasitic nematodes which have sucking mouth parts. Another less extensive group of viruses in this epidemiological class belongs to the tobacco rattle virus family. These are, as mentioned, rod-shaped viruses and are so far found to be transmitted by a single genus of nematodes distinct from those transmitting the ringspot viruses. Viruses seem to persist in nematodes, but the virus-vector relationship is not known with any precision.

Two genera of primitive fungi have so far been shown to serve as vectors of plant viruses. The relationship of these viruses with their vector not surprisingly varies with the virus. Big vein virus of lettuce, which is not mechanically transmissible, can survive for periods of up to eight years in the resting spores of its Olpidium vector. Tobacco necrosis virus, on the other hand, is easily transmitted and purified, but does not appear to survive to the same extent in resting spores of the same fungus. This virus may persist on colloidal particles in the soil and may

be acquired by the motile zoospores of the fungus from the soil or plant root surfaces and infect as zoospores enter the host. The precise association of these viruses with their vectors has yet to be solved.

Conclusion

ALTHOUGH the general structure of regular viruses is now understood with some degree of exactitude, much remains to be learned of the chemical interactions operative in various kinds of assembly. Available methodology has not yet fully been exploited and the next decade should produce significant advances in structure which will be applicable to many biological systems. It is still not clear how viruses enter plants nor are the details of multiplication known with satisfying precision. We still await plant tissue culture techniques applicable to most plant virus problems.

Vector relationships are known in broad outline, but important questions remain to be specified and new vectors and hosts will continue to appear. Most plant viruses so far known are restricted to angiosperm hosts and essentially all the vector studies have been concerned with agents which feed on angiosperms. However, plant viruses have been found in a primitive blue-green alga (in this case the virus is rather like a bacterial one—perhaps mimicking phylogenetic affinities), commercial mushrooms, a species of fern, and possibly in gymnosperms. There is no good reason why plant viruses should not commonly occur in plants phylogenetically less advanced than angiosperms and be associated in various ways with organisms which depend on them. For example, it would not be surprising if advances in our knowledge of food plants of the sea yield information about types of viruses and vectors unknown to us presently, and which introduce in turn new problems of epidemiology and control.

No new conceptual methods of controlling virus diseases on a large scale are evident, although what may be loosely regarded as interferon-like substances (plants do not make antibodies) are currently being studied to elucidate host-resistance mechanisms, and various heat-therapy methods are being better defined. Also, chemotherapy with nitrogen base analogues, for example, have received consideration particularly in the treatment of individual plants in conjunction with heat therapy and meristem culture techniques. However, breeding for resistance or escaping or controlling vectors through various cultural practices still seems the best course with large numbers of plants in commerce. Yet there may be better ways to combat disease, and continued studies on the actual properties and behavior of viruses should, apart from their considerable intrinsic interest which by itself is enough to justify much research, produce dividends in unexpected quarters.

The ultimate aim of plant pathology is to understand diseases so that they may be controlled economically. Our increasing knowledge of viruses and the diseases they cause makes it not unlikely that systemic viricides will be discovered and developed. We have seen tremendous advances in plant virus research in the past decade, and I think it safe to expect that the next 10 years will be equally productive.

The Changing Meanings of Virus

THE word "virus" has undergone successive limitations of meaning over the years. The Latin word of origin meant poison, slimy liquid, or offensive odor or taste. The original meaning is still found in the adjective "virulent." By 1728 the word meant a toxic substance produced in the body as a result of disease. In 1842 Dunglison defined virus as an agent for the transmission of infectious disease. Pasteur then discovered micro-organisms called bacteria, but viruses were still included in the latter term until Loeffler in 1898 found that foot-and-mouth disease could be transmitted by fluid filtered through infusorial earth, and, free from bacteria by examination and by culture. For the first part of the 20th century, these micro-organisms were called "filter-passing viruses," but the modifiers were eventually dropped; bacteriologists thus became microbiologists.

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THE MAKING OF A SCIENTIST

H. A. KREBS

I BECAME interested in my subject because students have asked me from time to time: "How does one become a Nobel laureate?". I have never before attempted to answer this question because I felt unable to offer an impromptu comment, but when the same question repeated itself I began to reflect on possible answers.

First, I must criticize the question as not being quite appropriate. What is appropriate is the related question: "How can distinction, or excellence, be attained in science?" Nobel awards are to some measure a matter of good luck, because their number is too small to do justice to all who would merit an award. A methodical way of finding an answer to the modified question is to study the history and characteristics of scientists of distinction. For this purpose I need a convenient criterion of distinction and, despite what I have just said (and despite some personal embarrassment), I will use the Nobel award as a mark of distinction, for want of a better criterion.

If I ask myself how it came about that one day I found myself in Stockholm, I have not the slightest doubt that I owe this good fortune to the circumstance that I had an outstanding teacher at the critical stage of my scientific career, when from my 25th to my 29th year I was associated with Otto Warburg in Berlin. He set an example in the methods and quality of first-rate research. Without him I am sure I would never have reached those standards which are a prerequisite for being considered by the Nobel Committees. I will say a few words later, on what in particular I feel I learned from him. But before doing this I would like to examine to what extent the importance of an outstanding teacher applies to other Nobel laureates.

Warburg himself was a Nobel laureate in 1931. He received the prize for his work on the chemical nature of a key enzyme in the reactions between molecular oxygen and foodstuffs in cellular respiration. I was lucky to witness this work from the closest quarters and to take a subsidiary part in it. What were the origins of Warburg's standards? In an autobiographical note (*1*) [1] which he wrote in 1964, he remarked that: "the most important event in the career of a young scientist is the personal contact

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[1] Italic numbers in parentheses refer to Literature Cited, p. 22.

with the great scientists of his time. Such an event happened to me in my life when Emil Fischer accepted me in 1903 as a coworker in protein chemistry. During the following three years I met Fischer almost daily and prepared, under his guidance, the first optically active peptides." So Warburg's experience and views are very much the same as my own. Let me follow up the story further.

Emil Fischer, Warburg's teacher, was one of the most outstanding chemists of his time. He was awarded a Nobel Prize in 1902 for his work on the chemical structure of sugars, the first of his long series of great achievements. Fischer in turn was a pupil and prolonged associate of another Nobel laureate, Adolf von Baeyer, who received the Nobel Prize after Fischer in 1905, for his discoveries in the field of the chemistry of dyestuffs, in particular for the synthesis of indigo.

Great Teachers

SINCE Nobel awards began only in 1901, this criterion of excellence cannot be used for the assessment of excellence in the 19th century, but the scientific "genealogy" of earlier teachers and pupils in figure 1 shows that von Baeyer was a pupil of Kekulé (famous for his contributions to the structure of organic compounds, especially the ring structure of benzene), and that Kekulé was a pupil of Liebig (who laid the foundation of organic chemistry). Evidently there was also an association with very distinguished teachers in the earlier generations of scientists; had Nobel awards existed in their time, Liebig and Kekulé would certainly have been laureates.

Berthollet	1748–1822
↓	
Gay-Lussac	1778–1850
↓	
Liebig	1803–1873
↓	
Kekulé	1829–1896
↓	
von Baeyer	1835–1917
↓	
E. Fischer	1852–1919
↓	
Warburg	1883 (born)
↓	
Krebs	1900 (born)

Figure 1.—Scientific genealogy

Liebig has provided his own testimony on the importance of a great teacher. He was a pupil of the French chemist Gay-Lussac, the discoverer of some of the fundamental laws of the behaviour of gases. At the time of Gay-Lussac and the young Liebig, Paris was the center of Continental science and of Continental chemistry in particular. Liebig worked under him in Paris and referred to this experience (*2*) in the following terms. "The course of my whole life was determined by the fact that Gay-Lussac accepted me in his laboratory as a collaborator and pupil." This is almost the same wording as that of Warburg, written 100 years later. Gay-Lussac was in turn a product of the great French school of chemists, including in particular Berthollet, who pioneered in the concepts of combustion (abandoning the phlogiston theory in favor of the role of oxygen) and elucidated the chemistry of chlorine, ammonia and hydrocyanic acid. One of Berthollet's teachers was Lavoisier.

In every case the association between teacher and pupil was close and prolonged, extending to the mature stage of the pupil, to what we would now call postgraduate and postdoctoral levels. It was not merely a matter of attending a course of lectures but of researching together over a period of years.

Scientific Genealogy

SO my scientific "genealogy" as summarized in figure 1 drives home the point that, in many instances, distinction breeds distinction or, in other words, distinction develops if nurtured by distinction. This is further borne out very forcibly by a consideration of a more extended family tree of scientists. Figure 2, derived from a chart exhibited in the Munich Museum of Science and Technology (Deutsches Museum), summarizes the genealogy of the Nobel laureates descended from von Baeyer, the pupil of Liebig, and this includes 17 names. Outstanding discoveries can be associated with all the names. A fuller chart (*3*), beginning two generations earlier with Liebig, contains more than 60 exceptionally distinguished names and includes more than 30 Nobel laureates.

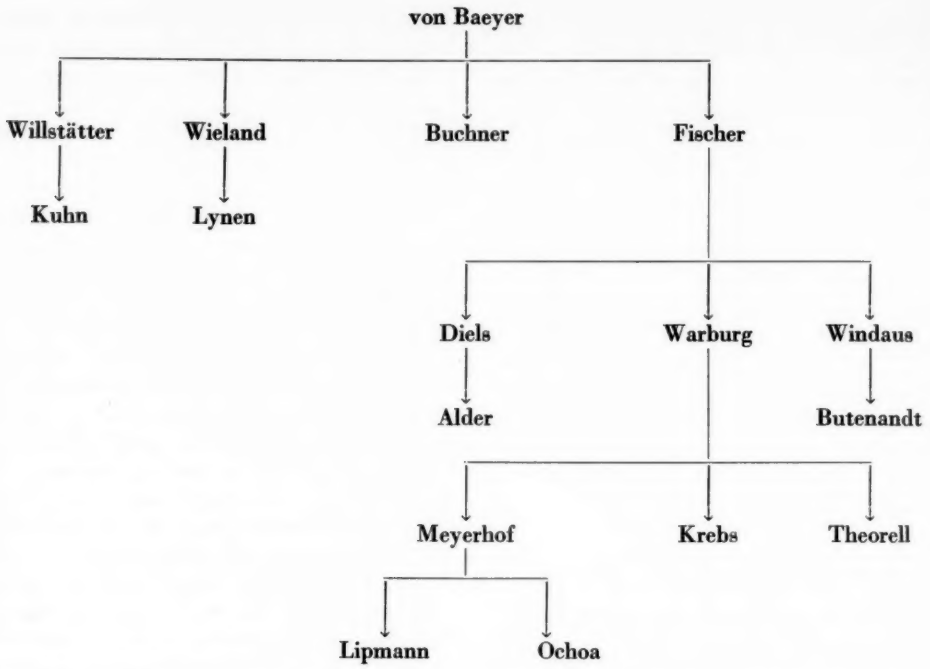

FIGURE 2.—Genealogy of the von Baeyer "family." The arrows indicate the teacher-pupil link. All members of this "family" are Nobel laureates.

Seeing this kind of agglomeration of laureates within a scientific family, the skeptic might well suspect a bias in favor of giving prizes to pupils of laureates. In short, does nepotism play a part in the awards? I hope everybody will agree that the answer to this question is an emphatic "No". The high standing, in the eyes of the world, of Nobel awards is derived from the general recognition of the absolute integrity of the Nobel Committees, and from the knowledge that these committees take a tremendous amount of trouble in finding the most worthy persons.

What, then, is it in particular that can be learned from teachers of special distinction? Above all, what they teach is a high standard of research. We measure everything, including ourselves, by comparisons; and in the absence of someone with outstanding ability there is a risk that we easily come to believe that we are excellent and much better than the next man. Mediocre people may appear big to themselves (and to others) if they are surrounded by small circumstances. By the same token, big people feel dwarfed in the company of giants, and this is a most useful feeling. So what the giants of science teach us is to see ourselves modestly and not to overrate ourselves. This is a general point.

Let me now try to be more specific and quote what individuals have themselves thought about the influence of their teachers. Warburg (*1*) in his autobiographical note summarized this with reference to his association with Emil Fischer: "I learned that the scientist must have the courage to attack the great unsolved problems of his time and that solutions can usually be forced by carrying out inumerable experiments without much critical hesitation."

If I try to summarize what I learned in particular from Warburg I would say he was to me an example of asking the right kind of question, of forging new tools for tackling the chosen problems, of being ruthless in self-criticism and of taking pains in verifying facts, of expressing results and ideas clearly

and concisely and of altogether focusing his life on true values.

An earlier witness on this question of what one learns from an outstanding teacher was Kekulé who, in 1890, when he was 61, remarked that above all he learned from his teacher Liebig the habit of hard work. He related (*4*) that Liebig had told him: "If you wish to be a chemist you must be willing to work so hard as to ruin your health. He who is not prepared to do this will not get far in chemistry nowadays." Kekulé added, "For many years four, or sometimes even three, hours of sleep were enough for me." Kekulé, of course, went a bit too far, quite a lot too far, but I do think there is a great deal of truth in attaching importance to the capacity for very hard work.

Opportunities

A RECENT witness on this question of what distinguished teaching can convey is Jacques Monod (*5*), who received a Nobel Prize in 1965. In his Nobel Lecture he commented on the importance to him of a Rockefeller Fellowship which gave him the opportunity to work at the California Institute of Technology in the laboratory of Morgan. He describes the influence which the contact with the distinguished people meant to his development as a scientist: "This was a revelation to me—a revelation of what a group of scientists could be like when engaged in creative activity, and sharing it in constant exchange of ideas, bold speculations and strong criticisms; it was a revelation of personalities of great stature such as George Beadle, Sterling Emerson, Bridges, Sturtevant, Jack Schultz and Ephrussi, all of whom were then working in Morgan's department." Morgan was at that time a Nobel laureate and Beadle became one later.

There is one more witness I want to quote in connection with the special qualities of what leaders in a subject can teach. This is Otto Loewi, who was a Nobel laureate in 1936, a pharmacologist and physiologist. He said this about the leading physiologists of the 19th century and their influence on their pupils (*6*): "They shared to the highest degree the qualities of contagious enthusiasm, broadmindedness and imagination, humility and deep devotion to their pupils. These are qualities which in themselves suffice to attract outstanding students. . . . Besides the art of experimenting and observing, the pupils learned the ways of thinking required by science. They learned how to select the object to be explored, how to interpret and evaluate the results obtained, and how to integrate them into the whole body of knowledge. In this way students were not only made familiar with methods and facts, but were imbued with the general scientific spirit which shapes the pattern of the true scholar and investigator."

So, above all, attitudes rather than knowledge are conveyed by the distinguished teacher. Technical skills can be learned from many teachers and, like a modicum of intelligence, are, of course, prerequisites for successful research. What is critical is the use of skills, how to assess their potentialities and their limitations; how to improve, to rejuvenate, to supplement them. But perhaps the most important element of attitude is humility, because from it flows a self-critical mind and the continuous effort to learn and to improve. Also of great importance is the enthusiasm conveyed from teacher to pupil: It is the root of a large capacity for work; it makes the research worker look on research not as work but as a hobby and it also induces him to say "No" when he is faced with tempting diversions leading him to the "corridors of power" or travel on innumerable trips abroad.

Asking the Right Questions

I HAVE referred to the importance of asking the right kind of question in choosing a research problem, avoiding those which may give a quick result and concentrating on those which are really worthwhile tackling. Paul Weiss (*7*) remarked: "The primary aim of research must not just be more facts and more facts, but more facts of strategic value." By strategic value he meant that an observation or an experiment should lead to the clarification of a problem or deeper insight into a phenomenon, or to the linking of previously unrelated facts and ideas. Goethe (*8*) expressed the same idea much earlier: "Progress in research is much hindered because people concern themselves with that which is not worth knowing, and that which cannot be known." Medawar (*9*) has recently stated very succinctly: "If politics is the art of the possible, science is the art of the soluble." How to select worthwhile soluble problems and how to create the tools required to achieve a solution is something that scientists learn

from the great figures in science rather than from books.

I would like to underline, on the basis of my own experience, what Monod said about the importance of belonging to a group of scientists such as he found in the California Institute of Technology. Association with a leading teacher almost automatically brings about close association with outstanding contemporaries of the pupil because great teachers tend to attract good people. Students at all levels learn as much from their fellow students as from their seniors and this was certainly true in my own case. Warburg's laboratory at Dahlem, where I served my apprenticeship, was surrounded by other centers of distinction. It was in the same building as Meyerhof's laboratory and the contacts between the two biochemical groups were very close. My own contemporaries included many young people who later became outstanding scientists. There were Ochoa and Lipmann, who became Nobel laureates. There was Lohmann, who discovered ATP and the structure of cocarboxylase; there was Karl Meyer, who discovered hyaluronic acid; there were Hans Gaffron, David Nachmansohn, Dean Burk, Frank Schmidt, Ralph Gerard and Hermann Blaschko. Among the numerous other outstanding scientists working within a few hundred yards, and getting together regularly at the weekly colloquia, were Neuberg, Hahn, Meitner, Haber, Polanyi and Bonhoeffer.

There are many other examples of such centers of excellence and breeding grounds of scientists. Cambridge, for example, was a center of excellence in physiology and biochemistry in the early decades of this century because Foster, Langley, Hopkins, Barcroft and Adrian were each surrounded by a group of enthusiastic young people of great ability. Cambridge, of course, at the same time was also a center of excellence in physics, thanks to J. J. Thomson and Rutherford.

No doubt Cambridge and Oxford owe some of their special standing to their size, which made it possible to assemble broadly based groups in a single subject at a time when provincial universities were usually restricted to very small departments with little scope for the cross-fertilization which occurs in the larger groups. It is gratifying to see the recent developments in the provincial universities which have removed this restriction and go a long way in providing a first rate environment.

What I have said so far is not merely a matter of historical reflections. There are lessons to be learned, in particular by policy makers in the universities who aim at making universities into centers of excellence. As excellence in research is one of the main ultimate roots of all academic excellence, including that of undergraduate teaching, universities ought to do everything in their power to create opportunities for first rate research work by their staff. But do they? Or, being willing, are they given the means, in terms of facilities and cash, to do so?

Leadership

IN the course of this century there have been only two *really* fundamental advances in the sciences: The first was in the field of atomic physics, leading to the creation of quantum mechanics and the release of atomic energy. The second was in biology where the fusion of biochemistry, biophysics and genetics to form molecular biology has led to an understanding of basic biological phenomena which, only a generation ago, seemed beyond the reach of science altogether. When we compare the circumstances which led to these two great advances we find, as Max Delbrück (*10*) has pointed out, remarkable differences in the manner in which they have been achieved. Atomic physics was created almost exclusively within the framework of traditional university institutions, whereas in biology the modern developments have not come from the traditional departments of biology. They are largely the results of the efforts of chemists, physicists and biologists, who frequently worked in non-biology departments, and outside the universities.

In Britain, decisive advances associated with the names of Wilkins, Crick, Watson, Perutz and Kendrew were made in the Medical Research Council units in London at King's College and at Cambridge, and both these units, financed by the Medical Research Council, were placed in physics and not in biology laboratories. In France, the decisive contributions associated with the names of Lwoff, Monod and Jacob came from the Pasteur Institute, an institution not controlled by a university. In the United States the Rockefeller Institute was a major contributor, through the work of Avery, MacLeod and McCarty, to the new developments. It is indeed most remarkable that universities allowed the initiative in advancing the frontiers of knowledge to slip

out of their hands in this way.

The loss of leadership in science by the universities is also borne out by statistics of the Nobel awards to British scientists, which are shown in table 1. Out of 18 British awards since 1950, only 10 laureates have earned their awards when holding university appointments—and at least one of them, myself, had a privileged appointment with very light teaching and administrative duties at the critical time. The statistics become even more telling when they are limited to the more recent times. Since 1960 only three Nobel awards went to the universities in Britain and five to non-university scientists (and this includes the physical sciences). In this table "other centers" means, in every case except one, the Medical Research Council's units. The exception is A. L. Hodgkin at Cambridge who holds a full-time research professorship of the Royal Society. In comparing these figures one has to bear in mind that the financial resources of the universities are very much greater, as a whole, than those of the Medical Research Council or the Royal Society. The funds at the disposal of the Medical Research Council were rather less than 5 percent of those available to the universities, and universities employ probably more than 10 times as many scientists as the Medical Research Council. In spite of this handicap, the Medical Research Council has a much larger share in the number of Nobel laureates.

Another illustration of this trend is provided by the statistics of the Fellowship of the Royal Society. Of 32 Fellows elected in March 1967, only 13 did their decisive work in the universities and some of these 13 were again in privileged positions within the university, occupying research posts without teaching commitments.

Why then have the universities lost their leading position in research? I believe the answer is simple. There is plenty of potential talent in British universities to achieve distinction in science; what is lacking is simply time. Real research of a fundamental character requires a tremendous amount of time. It cannot be done at odd spare moments, nor can it be delegated to technicians or Ph. D. students. The trouble is that senior and junior academic staff tend to be grossly overloaded with teaching, administration and college administration—in particular at Oxford. This overloading often begins at a very early stage of the academic career and leaves junior people insufficient time to mature during the postdoctoral stage. What scientists need for maturing are, I think, several postdoctoral years of essentially fulltime research before they embark on teaching on a major scale.

Another illustration of the importance of time for establishing academic standing is the relatively large number of university professors supplied by Medical Research Council establishments. Between 1961 and 1966, no fewer than 42 Medical Research Council staff went to universities to take up professorial appointments. This was possible because the Medical Research Council provides opportunities that universities cannot provide, giving scientists, above all, enough time. Thus Medical Research Council establishments have proved to be very effective breeding grounds for scientists suitable for senior university posts. I ought to emphasize that it is quite wrong to blame the Medical Research Council (as has been done) for keeping some excellent people away from the universities, when these people, after

TABLE 1.—*British Nobel awards since 1950*

Universities (10)		Other centers (8)	
C. F. Powell	(1950)	A. J. P. Martin	(1952)
J. D. Cockcroft	(1951)	R. L. M. Synge	(1952)
E. T. S. Walton	(1951)	F. Sanger	(1958)
H. A. Krebs	(1953)	F. M. Perutz	(1962)
M. Born	(1954)	J. C. Kendrew	(1962)
C. N. Hinshelwood	(1956)	F. H. C. Crick	(1962)
A. R. Todd	(1957)	M. H. F. Wilkins	(1962)
P. B. Medawar	(1960)	A. L. Hodgkin	(1963)
A. F. Huxley	(1963)		
D. C. Hodgkin	(1964)		

maturing, return to the universities well prepared for senior appointments.

Research, unlike routine jobs such as teaching or doctoring or administration, needs a minimum critical effort to be effective, and this minimum is very demanding in time. I have often heard it said by those university people who do not know what scientific research means, "Well, if you only have half the amount of time you feel you ought to have, cut down your research by half. What does it matter?"

This reasoning is false. It is like the idea that in order to cut down the noise of an airplane engine, the speed of the engine should be reduced. Up to a limited point, of course, this works and the aircraft just travels more slowly. But soon there comes a point when it will no longer remain airborne. At low engine speed it can still taxi along the ground, but that is all.

The Research Team

SCIENTIFIC research requires a high minimum critical momentum. Effectiveness in research is not just proportional to the effort. The scientist who has insufficient time may manage to taxi along over well ploughed grounds but he will have the greatest difficulty in becoming airborne—doing something really new and original. On the other hand, once he has gathered momentum he will soon find himself in new and unknown territory. One of the most effective ways of attaining a powerful momentum is belonging to a team. Contrary to what some may feel, membership of a team does not at all imply loss of individual scope, of individual initiative, of individual achievement, of indivdual recognition. What the team provides is a background of aggregate skill, experience and help. This background forms the starting point for individual enterprise.

In the last resort, then, the reason for failing to obtain excellence, in spite of great potentialities, is in many cases the circumstance that those responsible for the organization of the lives of scientists rob them of time.

All this leads to the large question of whether our universities today do as much as they ought to in providing centers of excellence in science, a matter taken for granted a generation ago. In many American universities this a frequent subject for discussion, and it is perhaps signficant that the former United States Secretary for Health, Education, and Welfare, John Gardner (*11*) has written a provocative book called *Excellence* with the subtitle "Can we be equal and excellent too?" I am not at all sure whether our main financial sponsors, the University Grants Committee and in particular the Treasury, give sufficient thought and money to the importance of cultivating excellence in the universities; to the fact that in science, teaching and research always go together and that in this age of science the cultivation of excellence in science is not an academic exercise but a source of economic and political strength.

My own apprehensions are naturally influenced by my personal experience at Oxford, where, under the banner of equality and democracy, circumstances operate powerfully against the development of excellence in science. In quite a few spheres of the life of this country, I fear we have too much equality and too little promotion of excellence. At Oxford very few of the excellent young scientists are given a chance to develop their potentialities in scientific research, merely because they are deprived of the time. A large number of promising and distinguished scientists have for these reasons left Oxford or refused appointments there. This might benefit other British universities if they can show themselves more sympathetic or able to help them, but lack of opportunities, especially in terms of time, has also contributed towards the "brain drain."

Unless we in the universities are aware of these problems and continuously strive for the maintenance of high standards, we are bound to deteriorate. This is a matter of general concern to university people.

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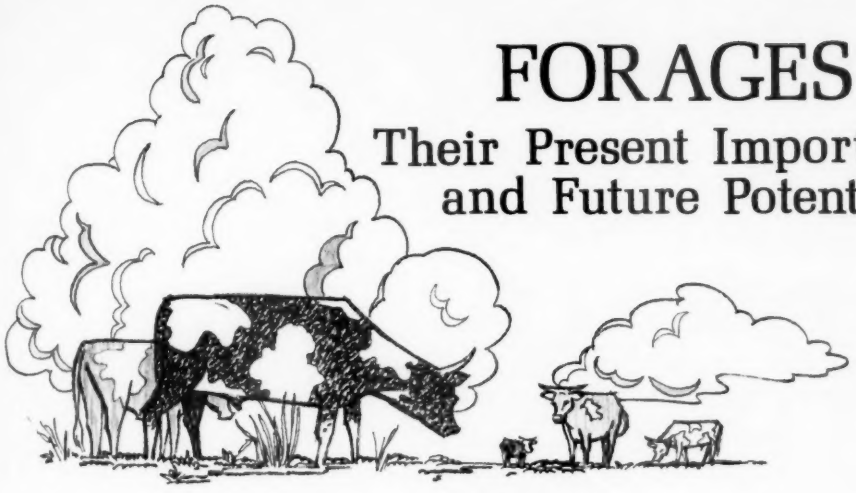

FORAGES

Their Present Importance and Future Potentials

H. J. HODGSON

THE United States posseses a rich bounty in the magnitude of its grasslands. Over half of our total land area—about a billion acres—produces forage. And of the total land area in farms, 62 percent—or about 700 million acres—is classed as forage-producing land (*11*).[1]

The forages produced on these lands very tremendously in kind, yield, and quality. But they all have one thing in common: little or no value until they are marketed through livestock—principally cattle—and in this form they have an estimated annual value of about $8 billion (*4*).

Forages provide more than half the feed units consumed by all livestock (table 1). In 1965, dairy cattle obtained two-thirds and beef cattle three-fourths of their feed units from forages. (A feed unit is the equivalent of one pound of corn.) Other ruminants and horses obtained greater proportions of feed units from forages although total consumption was considerably less.

The estimated annual value of forages about equals cash receipts from cotton, soybeans, wheat, tobacco, and rice (table 2). The value of the corn crop averages about 60 percent of the value of forages. Since about 85 percent of our corn is fed to livestock (*12*), it therefore—like forages—has much reduced value until marketed through livestock.

Because forages have utility largely as ruminant feed, forage crop researchers need to be continually aware of the trends in cattle production in order to maximize the forage contribution. Such emphasis has not always been evident in the past. Few crop varieties we use today have been developed with efficiency of animal utilization in mind. Most selection has been made on the basis of yield of dry matter, disease or insect resistance, hardiness, and other non-animal-oriented factors. Research in forage management has had only slight consideration for the animal.

In attempting to assess the important forage crop problems of the next decade or two, we must first determine what the forage requirement of ruminants are likely to be. To do this, we first need to examine recent trends in cattle numbers, feeding practices, and projected requirements for beef and dairy products.

Table 3 shows trends in populations of dairy and beef cattle over the past two decades. Note the decrease in dairy cattle and the sharp increase in beef cattle numbers. Note also the change in the proportion of cattle on feed to other beef cattle from almost 1:6 in 1949 to almost 1:3 in 1966. This decreased ratio probably reflects the recent trend toward moving cattle into feedlots at lighter weights.

[1] Italic numbers in parentheses refer to Literature Cited, p. 30.

TABLE 1.—*Percentage of feed units consumed by livestock from concentrates and forage, 1965*

	Concentrates	Forages
	Percent	*Percent*
All livestock	47	53
Dairy cattle	34	66
Beef cattle	22	78
Sheep and goats	11	82
Horses and mules	22	78

USDA Stat. Bull. 337—1967 Supplement.

TABLE 2.—*Value of major field crops*

	1965	1966
	Billion dollars	*Billion dollars*
Corn [1]	4.800	4.920
Cotton	2.354	1.579
Soybeans	1.940	2.524
Wheat	1.603	2.025
Tobacco	1.186	1.210
Rice	.374	.405
Potatoes	.781	.587
Sugar beets	.237	.245
Peanuts	.279	.270

[1] Calculated from Feed Situation Fds-220, 1967.

USDA, FIS 203, August 1966 and 1967.

TABLE 3.—*Populations of dairy and beef cattle*

	1949	1959	1966
	Millions	*Millions*	*Millions*
Milk cows	23.8	19.5	15.2
Other dairy	12.6	11.0	7.7
Cattle on feed [1]	6.5	13.1	22.0
Other beef	35.1	58.1	64.1

[1] Number fed during year.

USDA Stat. Bull. 337 (1966) and 397.

TABLE 4.—*Consumption of concenirates by cattle, per head*

	1949	1959	1966
	Pounds	*Pounds*	*Pounds*
Milk cows	1,558	2,495	3,279
Other dairy	458	628	699
Cattle on feed	2,399	2,191	2,455
Other beef	185	195	220

USDA Stat. Bull. 377 (1966) and 379

Table 4 shows the trends in consumption of concentrates during the past two decades. The amounts fed to beef cattle have remained essentially unchanged on a per-head basis. For dairy cattle, however, the rates of concentrate feeding have gone up sharply. Also, use of pastures by dairy cattle has markedly decreased and corn silage use has increased.

The principal reasons for the increase in concentrate feeding to dairy cattle are as follows: (a) the abundance, low cost, and high quality of feed grains, together with easy mechanization of feeding them, (b) low quality hay, (c) low relative yield of forages, (d) quality deterioration, costs, and dry matter losses accompanying forage harvesting, and (e) scarcity of competent farm labor.

FUTURE FORAGE NEEDS

THE Long Range Study (LRS) (*10*) estimates needed increases in agricultural production of about one-third by 1980 and double by 2000. This estimate is, of course, an average of all production; the need for some products will increase rapidly and for others less rapidly. Demand for beef, for example, is expected to increase 45 percent in the next 10 years. Demand for milk will increase at a much slower rate because consumption per capita is declining.

To estimate the demands for forage needs, we need to convert the projected demand for food needed for human consumption to feed requirements of cattle. Although this conversion is most difficult to make, some generalizations seem possible. To achieve the 1980 and 2000 LRS goals, annual average productivity gains of 2.2 and 3 percent respectively would be required. Crop output gains per acre have ranged from about 2.5 to 3 percent in the past 15 years (*3*). It seems rather reasonable to expect similar gains in the next decade or two. Forage productivity gains probably have been on the low side over the past 15 years.

If we assume the LRS goals can be met, and if we assume the same 1966 ratio of cattle on feed to other beef cattle will continue—then we would need to have on U.S. farms by 1980 some 29 million cattle on feed (up 7 million) some 85 million other beef cattle (up 21 million). By 2000 we would have 44 million on feed and 128 million other cattle—twice the present number. If increases in per-capita consumption of red meat continue, still greater beef cattle populations will be required. The picture for dairy cattle is not so clear, because per-capita consumption of dairy products has been declining and per-cow outputs have been rising. The decline in dairy cow numbers probably will level off some during the next decade. Total production will increase, however; and with it, feed requirements will also increase.

High-producing dairy cows are the most profitable, because most overhead costs are similar for cows at all levels of production. Average production per cow has increased to 8,513 pounds, an average yearly gain of 220 pounds since 1957. Higher production per cow has required liberal grain feeding because forages have been incapable of supplying the required nutrients. But with higher grain feeding

has come increased production costs. In 1954 30.2 pounds of concentrates were fed per 100 pounds of milk; in 1966 37.8 pounds were fed (*11*). DHIA data show that costs of concentrates fed per 100 pounds of milk were $0.91 and $1.12 in 1957 and 1966 respectively. The profitability of higher production is closely associated with grain-milk price ratios. Since neither is strongly controlled by dairymen, the possibility of limiting cost or increasing profit through manipulation of this ratio is decidedly limited. Dairymen are now in a tight cost-price squeeze. If feed grain prices should increase, the squeeze will become tighter. Failure of grain crop production to increase at a rate sufficient to meet both human demands and ample supplies for cattle could cause higher prices and intensify the squeeze. This background emphasizes the great importance in the next decade of providing: (a) increased amounts of forage with higher nutritional value and intake levels for dairy cattle, (b) lower forage production and handling costs, and (c) highly automated feeding and transport systems for forage in various forms.

Only about one-fourth of the beef cattle in the country in any one year are in feedlots and are consuming high-grain rations. About three-fourths are breeding animals, calves, etc., which receive about 92 percent of their feed units from forage. This ratio probably will decrease only slightly over time and could reverse with higher priced feed grains. Therefore, for every additional animal in the feedlot we need about three more in breeding herds, etc. Thus, increasing the numbers of fattened cattle requires substantial numbers of other cattle. With prices for beef calves prevailing now or in the future and with anticipated trends in feed grain prices, it does not seem probable that concentrates can be fed to breeding herds to any great extent. Perhaps questionable also, but to a lesser degree, is the practice of feeding roughages to cows in drylot. But two things *are* clear. We will need vastly increased outputs of forage production in the next two decades. The greatest portion of this forage will be fed to beef cattle.

Two factors may profoundly affect the types of forage fed to cattle in the future (*6*). The first is the use of non-protein nitrogen to supply large fractions of the nitrogen supplies of ruminants. Although only limited amounts can be fed now, further research probably will materially increase levels of feeding non-protein nitrogen. About 125,000 metric tons of urea are now fed annually. If urea is produced cheaply enough, widespread feeding could materially change our conception of quality forage. High protein content may become of reduced importance and high dry-matter digestibility of greater importance.

The second factor seems more remote, but if it proves economical it could have great significance. I refer to chemical treatment of forage to increase digestibility of high-lignin materials by ruminants. At this point, it is too early to forecast the extent to which this process will be economically useful. But we have large quantities of low quality, high-lignin materials. Improvement in digestibility of this material plus urea feeding could have profound effects. Forage researchers should watch developments in these areas very closely.

FORAGE RESEARCH NEEDS

WE are making poor use of the technology already available in the production of forage crops. Yields could be materially increased by:

1. Greater use of fertilizers, particularly when forages are to be harvested mechanically and either stored or fed green. Per-ton harvesting costs could be materially decreased if higher yields were available. We have reams of research data—so much in fact that it might be questioned whether we need much more—indicating that dry-matter yields can be increased by fertilizers. But perhaps we have not adequately defined the economic advantages of increasing fertilizer usage.
2. Wider adoption of management practices tailored to produce the quality of forage required for the class of livestock using it.
3. More widespeard usage of superior varieties already developed.

Yet we do need considerable new technology. Obtaining it will require closer cooperation among forage physiologists, forage breeders, engineers, animal nutritionists and others.

Forage Conservation

ONE of the principal limiting factors in forage production today deals with forage conservation.

Mowing and post-mowing operations account for about half the cost of producing hay. Moreover, during the harvesting and storage operations we lose about one-third of the feed value in the standing crop. In addition, the harvesting, storage and feeding processes still require considerable hard labor and sometimes offer resistance to maximum mechanization and transport. Compare these disadvantages with methods of harvesting and utilizing corn, for example. Would a corn farmer be content to leave every third row of corn in the field? New approaches, therefore, are needed in handling preserving, packaging, and feeding forages. Unless this bottleneck is overcome, gains from other achievements we might make will have less impact. We need very badly a sizeable, well coordinated, and concentrated effort directed to solution of these important problems.

Biological Efficiency

WE need still better forage crop varieties—both annual and perennial—with higher yield potential and higher dry matter digestibility. Disease and insect resistance must also be maintained or increased. Our gains in genetic potential for yield have not been spectacular in most forage crops, with the exception of a few instances where asexual reproduction is possible, and even in these cases more potential for improvement exists. Perhaps one reason for the slow progress, in spite of considerable breeding effort, is the fact that our current techniques for evaluating genetic potential are so imprecise that we cannot exert sufficiently severe selection pressures on populations. We have probably established an artificial yield barrier with our breeding systems, and substantial progress awaits more precise evaluation of biological efficiency on an individual plant basis. The plant breeder needs an input from the physiologist to develop adequate techniques for identifying superior biological efficiency on an individual plant basis.

Biological efficiency involves numerous plant processes, two of which are photosynthetic efficiency and the rate at which photosynthetic area is produced or expanded. There is, therefore, a critical need for devising methodology for rapid measurement of these characteristics so that large numbers of plants can be evaluated individually. Perhaps we will need to evaluate photosynthetic efficiency at light saturation and also at considerably reduced intensities similar to those in solid stands of forages. It is not essential that measurements be extremely precise but good repeatability is necessary. What is required is methodology to realistically spread plant populations on a scale to permit exercising high selection pressure. Once higher biological efficiency is identified and isolated, plant breeders will be able, in a relatively short time, to determine heritability and methods of combining highly efficient plants into varieties. If high efficiency is found in varieties with good adaptation and disease and insect resistance, highly improved varieties would follow quickly. If it is found in unadapted sources, the breeding process will require more time.

Additional information is needed on the relationship of morphological and anatomical characteristics to biological efficiencies of individual plants and solid stands. Cooper and associates (*9*), working with grasses at Aberystwyth, Wales, discovered that differences in rate of photosynthesis per unit leaf area of various genotypes depended on the interaction between mesophyll thickness and the number of mesophyll cells below unit leaf area. If this relationship holds true generally, selection on the basis of leaf anatomy might prove practical. We need also to know much more about the relation between leaf orientation and display on the efficiency of solid stands of forage crops.

Finally, we might improve our efficiency of selection by using higher nutrition and management input levels to enable more rigorous selection pressures.

Higher Dry Matter Digestibility

BECAUSE forages are of value chiefly to ruminant animals, proper evaluation must rest on measuring real or predicted animal performance.

Methods now are available to evaluate dry matter digestibility (DMD) on a single plant basis. Although some researchers might question the accuracy of some methods, they do provide a satisfactory means of spreading populations on a curve for selection purposes. The Tilley-Terry, nylon bag, chemical (Van Soest) and possibly other methods all can be useful in this regard.

The first variety developed and released on the basis of selection for DMD was Coast-Cross Bermuda, which probably will replace Coastal in many

areas. DMD was 12 percent higher and animal performance 30 percent higher than that of Coastal (2). Particularly interesting in this work was the finding that correlations between DMD and conventional estimates of quality (percentage of dry-matter, protein, leaves, and crude fiber) were too low to be of value in selection. Does this tell us that these are also poor criteria for evaluating effects of management practices?

We now know that a considerable range of variation in DMD exists in many forage species. Julén and Lager (5) reported significant and heritable plant-to-plant differences in *in vitro* DMD in orchardgrass. Mowatt (7) reported that (a) orchardgrass plants ranged from 49 to 68 percent DMD and 73 percent of the variation was genetic, and (b) bromegrass leaves ranged from 66 to 76 percent and stems from 58 to 73 percent DMD; coarseness was not related to DMD.

Considerable variation in DMD probably exists in all species if we will look for it in a wide range of genetic material. There seems to be no reason why annual forages should not also show similar ranges of variation in DMD, and selection on this basis should be very profitable. Animal nutritionists may identify certain chemical components which are desirable. Selection then should proceed for these factors as well as DMD.

Since we know there is a significant variation in DMD among individual plants, is it not reasonable to also expect plant-to-plant differences in the rate at which DMD decreases with maturity?

Some Researchable Questions

HIGHER biological efficiency of varieties and higher digestibility of the dry matter produced are goals that may require new information. Some researchable questions, among others, which should be answered are as follows:

1. Leaves of grasses deteriorate in photosynthetic efficiency with age, and the period of highest efficiency is not especially long. Does this decline occur in all grasses? Does it occur at the same rate in all species or in all plants within a species? If not, are plant-to-plant variations of sufficient magnitude to warrant selection for types with slower decline in efficiency?
2. What happens to DMD when the leaf blade declines in photosynthetic efficiency? Does it decline also as one might expect?
3. What is the relation of optimum leaf area index and maximum utilization of radiant energy to the decline in photosynthetic efficiency? Does this tell us something of significance in devising the most effective management systems for forages?
4. Is there a physiologic advantage to annual crops? Perennials divert sizeable portions of photosynthate to storage of reserves for regrowth and overwintering. Does the earlier and later growth of perennials together with associated labor and conservation values offset this? Most annuals tolerate hot summer weather better than perennials. Active growth in this period takes advantage of greater light intensity and duration. Can we find perennials with minimum storage requirements except in autumn? Can we find perennials with greater tolerance to heat and drought and which will maintain productivity under periods of highest light duration and intensity?

Any seed-propagated forage crop variety must have the ability to produce profitable seed yields in order for it to enter commercial channels. Many vigorous plants are discarded from breeding programs because they are poor seed producers, even though they may be superior in all other respects. These plants produce numerous tillers, but relatively few undergo floral induction and initiation and plants remain largely vegetative. Our knowledge of the biochemistry of floral induction and initiation, especially in perennial grasses, is very limited. Detailed knowledge of these processes might allow manipulation of floral induction and permit control of the flowering process—either enhancing or restricting it as desired—by spraying with appropriate chemicals at appropriate times. This would result in maximizing seed yields and permit utilization of considerable germplasm with high biological efficiency, disease and insect resistance but which is poor in seed production capability.

The Payoff

COMBINING higher genetic potential for yield and higher DMD into adapted varieties should make forages strongly competitive with other crops,

even on the better soils, and greatly increase the profitability of our forage-based beef cattle and dairy industries. A 30-percent increase in animal performance accompanying a 12-percent increase in DMD in bermudagrass obtained by Burton, *et al* (*8*) is indicative of the potential gains from increasing digestibility of our forages. Dry matter yield increases of 20 to 25 percent should easily be achieved through effective selection of the components of biological efficiency (photosynthetic efficiency and growth rate among others). It has been estimated that forage dry-matter yields could be doubled by application of fertilizer technology now available. Thus, the increased digestible dry-matter production capacity of forage is potentially very great.

But production of higher yields of higher quality forage by using varieties with higher biological efficiency and improved management requires re-examination of present day harvesting techniques. For example, are high management and production inputs compatible with a livestock management system based on grazing? At what level do further inputs become uneconomical in a grazing system? Have we properly defined the economic relationships between levels of production and management inputs and methods of harvesting or utilization? Further, as the feed value per unit of dry matter is increased, the dry-matter losses of present day harvesting and processing methods become more intolerable and the demand to find improved methodology of the harvesting, processing, and storage processes becomes greater.

LEAF PROTEINS

WE have traditionally considered forages as livestock feed. But we are beginning to realize the potential of these crops as sources of protein for humans. Literature on this subject is steadily increasing. Two facts are significant: (a) yield of leaf protein per acre greatly exceeds that of seed protein and (b) the quality of leaf proteins is generally superior to seed proteins, approximating the quality of meat or milk proteins. For example, leaf protein concentrates contain about twice as much lysine as high lysine corn and more methionine than soybean protein. Recent papers by Akeson and Stahmann (*1*) of Wisconsin and by Pirie (*8*) of the Rothamstead Experiment Station in England give a good prospectus of the potential of leaf proteins for satisfying human protein requirements on a world basis. Research on this subject however has been decidedly limited when compared to that devoted to seed proteins, fish meals, algae, and other sources. In this country we now are engaged in extensive research on improving protein quality of cereal grains, but relatively little attention is being given to utilization of leaf proteins—many of which already possess the desired quality.

FORAGES AS A SYSTEM

WE need to look at forage production and utilization as a system in which alterations in inputs or methodology in one part of the system affect the

other parts of the system. Researchers and administrators concerned with the system need to define the important researchable questions of the next decade or two pertinent to this system. The additional information required to answer the questions can be identified. Cooperative research between disciplines and between various public agencies, State and federal, can be planned to provide the needed information. Some of the research may be quite basic, some quite applied. But the time when cooperation is most needed is in the research planning stages when problems are identified and questions formulated. This should require cooperation between the disciplines of economics, plant breeding and genetics, plant physiology, engineering, animal nutrition, animal breeding and genetics, soils, plant pathology, entomology and perhaps others.

Such an approach to forage research could well result in substantial realignment of approximately 500 science-man-years devoted to forage research in the United States. The challenges of the next few decades demand that this be accomplished.

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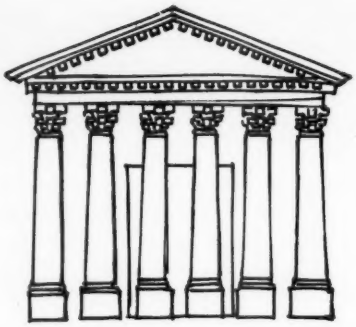

FORUM

AGRICULTURE NEEDS MORE YOUNG PEOPLE

"WHEN tillage begins," Daniel Webster once remarked, "other arts follow. Farmers, therefore, are the founders of human civilization." They may be its most essential stewards as well, for throughout history the level of living enjoyed by any people has been dependent upon the success of its agriculture.

American agriculture has been successful beyond imagination. Today, only about 6 percent of our population produces all of our food and much of our fiber needs. Perhaps as a result of this remarkable achievement, the nation appears to be losing sight of the need to encourage, rather than discourage, capable young people to pursue a career in agriculture. This alarming trend, if seems to me, is due largely to a lack of understanding—both of the need and the opportunities at hand.

Not an Easy Way of Life

THE American people generally feel that farming *per se* is neither an easy nor a financially rewarding way of life. Hence, they are reluctant to see their children become farmers.

For example, a recent study indicates that while most Oregon citizens are aware of agriculture's importance in this State, they tend to depreciate its occupational potential. Out of 10 leading industries, the public ranked agriculture only sixth in occupational promise. College-educated business leaders, in particular, ranked it as one of the least promising occupations.

A High-Risk Business

MANY Oregon citizens think of the farmer as having limited job security and of agriculture as a high-risk business. Many feel that the farmer's financial return is neither commensurate with his efforts nor equivalent to other industry standards. And many express the view that "it just takes too much money to get started in farming today."

To be sure, the average farm investment has increased more than tenfold since 1940, although average return on the farm investment has decreased by about 40 percent. National income has risen by 230 percent in the past 20 years, but farm income has declined by 9 percent. And while retail food prices have increased by about 40 percent during the past two decades, prices received by farmers in 1966 were about 2 percent lower than those received during the 1947–49 period.

Such developments make it less difficult to understand the declining interest in encouraging young people to otbain an education in agriculture. *But to understand is not to accept.*

Food Production and Demand

FIRST, we must come to realize some hard facts of life concerning:

- The increase in world population. It is a matter of record that births are exceeding deaths by about 60 million annually—enough people to populate each year a new country the size of France.
- The extent of world hunger. Nearly two-thirds of the world—about 1.5 billion people—goes to bed hungry every night. Approximately 10,000 people die every day because of inadequate diet. The World Health Organization estimates that 3.5 million youngsters die every year from hunger and various diseases associated with malnutrition. Millions more are physically and psychologically crippled.

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- The world demand for food production. World food production in 1965 was about the same as in 1964, but there was a net gain of 63 million people during 1965. Between 1961 and 1965, the amount of food available to each person declined by 4 percent in Asia and by 6 percent in Latin America. With the anticipated population growth during the next 30 years, world food production will have to be increased by 80 percent just to maintain current levels of consumption. Many nations will have to double, and some nations triple, their food output merely to stay even.

Our Number-One Industry

SECOND, we must not fail to realize that:

- Agriculture continues as America's number-one industry and the cornerstone of our economy. Nearly one-third of all the productivity-employed people in this country are engaged in some phase of the dynamic agribusiness complex.
- Agriculture is fundamentally a wealth-producing industry operating on a base of renewable resources. For every $1 worth of product leaving our farms, another $1 to $2 is generated in the economy as this farm product moves into the channels of consumption.
- The reason 94 percent of our population presently is enabled to pursue somthing other than the active production of farm products is the acquired "know-how" of the other 6 percent, combined with the use of expensive machines and materials.
- One of history's really vital lessons is that food-deficient countries start their decline by not paying sufficient attention to the protection and development of their basic natural resources. Common pitfalls include insufficient provision for research, inadequate control of insects and diseases, and improper management of the capacity to produce food, clothing, and shelter. It is worth noting that even the United States will have to increase food production by 30 percent within the next 20 years to maintain its current level of consumption.

Clearly, the need for young people in agriculture has never been greater. Graduates of colleges of agriculture are in very short supply. The national ratio of jobs to holders of a B.S. degree in agriculture is more than two to one. And in certain regions, the ratio is considerably higher.

It is forecast that by 1980, fully half the Nation's farmers and ranchers will own agribusinesses with capital requirements of more than $150,000. Most of these will continue in the "family-operations" category. One out of every ten agribusinesses will carry an investment in excess of $325,000. These modern agricultural "factories" will want properly qualified management personnel.

In the minds of all too many, however, agriculture still means farming. The fact is that many of the things we used to do on the farm have moved to town. This is a logical part of our industrialization, and the people who make it work are mostly agriculturists, trained and educated in modern agriculture. Thus, industry offers virtually unlimited opportunity in fields such as chemicals and fertilizers, marketing, processing, finance, engineering, transportation, communications, farm organizations, and farm services, to name but a few.

Other Opportunities Await

NUMEROUS opportunities also await young people in agricultural education, research, and development, and in State and Federal services. The opportunity abroad speaks for itself.

If we ever are to meet the needs of all mankind, including a degree of peace and release from famine, disease, and pestilence, we must have personnel who can lead the way. Hunger, starvation, and the many miseries that accompany them can be brought to a point of acceptable tolerance—but not unless we provide our own people and the world with young men and young women who have the knowledge and the skill to do the job.

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